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A current and future state of art development of hybrid energy system using wind and PV-solar: A review

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ABSTRACT

The wind and solar energy are omnipresent, freely available, and environmental friendly. The wind energy systems may not be technically viable at all sites because of low wind speeds and being more unpredictable than solar energy. The combined utilization of these renewable energy sources are therefore becoming increasingly attractive and are being widely used as alternative of oil-produced energy. Economic aspects of these renewable energy technologies are sufficiently promising to include them for rising power generation capability in developing countries. A renewable hybrid energy system consists of two or more energy sources, a power conditioning equipment, a controller and an optional energy storage system. These hybrid energy systems are becoming popular in remote area power generation applications due to advancements in renewable energy technologies and substantial rise in prices of petroleum products. Research and development efforts in solar, wind, and other renewable energy technologies are required to continue for, improving their performance, establishing techniques for accurately predicting their output and reliably integrating them with other conventional generating sources. The aim of this paper is to review the current state of the design, operation and control requirement of the stand-alone PV solar–wind hybrid energy systems with conventional backup source i.e. diesel or grid. This Paper also highlights the future developments, which have the potential to increase the economic attractiveness of such systems and their acceptance by the user.

Contents

1. Introduction

One of the most promising applications of renewable energy technology is the installation of hybrid energy systems in remote areas, where the grid extension is costly and the cost of fuel increases

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drastically with the remoteness of the location. Recent research and development in Renewable energy sources have shown excellent potential, as a form of supplementary contribution to conventional power generation systems. In order to meet sustained load demands during varying natural conditions, different energy sources and converters need to be integrated with each other for extended usage of alternative energy. Renewable energy sources, such as photovoltaic, wind energy, or small scale hydro [28,49], provide a realistic alternative to engine-driven generators for electricity generation in remote areas [39,66]. It has been demonstrated that hybrid energy systems can significantly reduce the total lifecycle cost [4] of stand-alone power supplies in many situations, while at the same time providing a more reliable supply of electricity through the combination of energy sources [3,44]. The widely used term hybrid energy system (HES) describes a stand-alone energy system [57], which combines renewable and conventional energy sources with lead-acid batteries for chemical storage, power conditioning equipment and a controller. The controller and power conditioning units [1,12] are used to maintain the grid quality power [70]. Alternatively, such systems are also known as integrated renewable energy systems (IRES). The concept of hybrid energy system is shown in Fig. 1 in this system the conventional system either diesel generator or grid are used as a back-up generator.

Various hybrid energy systems have been installed [15,18] in many countries over the last decade, resulting in the development of systems that can compete with conventional, fuel based remote area power supplies [2] in many applications. Research has focused on the performance analysis [16,52] of demonstration systems and the development of efficient power converters, such as bi-directional inverters, battery management units. Maximum power point trackers [41,58]. Various simulation programs [71] are available, which allow the optimum sizing of hybrid energy systems.

The recent state of art hybrid energy system technological development is the result of activities in a number of research areas, such as

- Advances in electrical power conversion through the availability of new power electronic semiconductor devices, have led to improved efficiency, system quality and reliability.
- Development of versatile hybrid energy system simulation software; continuing advances in the manufacturing process and improve efficiency of photovoltaic modules.
- The development of customized, automatic controllers, which improve the operation of hybrid energy systems and reduce maintenance requirements.
- Development of improved, deep-cycle, lead-acid batteries for renewable energy systems.
- Availability of more efficient and reliable AC and DC appliances, which can recover their additional cost over their extended operating lifetime.

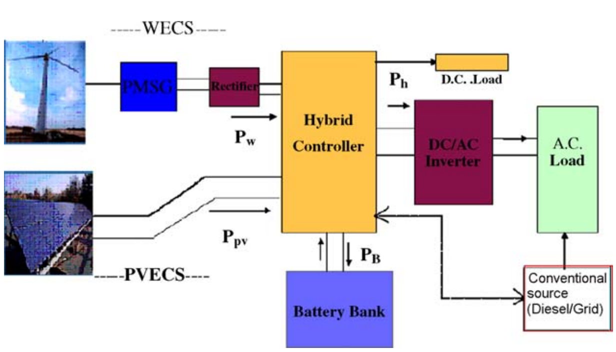

Fig. 1. Concept diagram of hybrid energy systems.

- The task for the hybrid energy system controller is to control the interaction of various system components and control power flow within the system to provide a stable and reliable source of energy.

With the wide spread introduction of net-metering, the use of small isolated or grid connected hybrid energy systems is expected to grow tremendously in the near future. The aim of this paper is to review the current state of the design and operation of hybrid energy systems, and to present future developments, which will allow a further expansion of markets, both in industrialized and developing countries.

2. Pre-feasibility analysis of hybrid system

Climatic conditions determine the availability and magnitude of wind and solar energy at particular site. Pre-feasibility studies are based on weather data [3] (wind speed, solar insolation) and load requirements for specific site. In order to calculate the performance of an existing system, or to predict energy consumption or energy generated from a system in the design stage, appropriate weather data is required. The global whether data could be obtained from internet [74] and other sources like local metrological station. The global weather pattern is taken from NASA surface metrological station shown in Figs. 2 and 3. In Fig. 2 the red and yellow indicate high wind energy is available while the blue colors reflect lower wind energy potential zone. Fig. 3 shows the solar insolation level at different areas of the world. Wind and solar hybrid system can be designed with the help of these global weather patterns, for any location all over the world. Deciding on the best feasible solution will need to be done, on a site-to-site basis. Some sites can be best serviced by mains or grid power, others by generators, and some by combinations of the renewable energy solutions described above.

Some researchers used metrological station data for pre-feasibility study and design of hybrid energy system. Combination of PV and wind in a hybrid energy system reduces the battery bank and diesel requirements. Feasibility of hybrid PV/wind energy system strongly depends on solar radiation and wind energy potential available at the site. Various feasibility [38] and performance studies are reported to evaluate option of hybrid

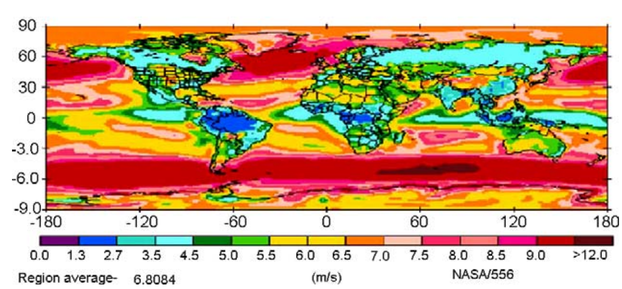

Fig. 2. Global wind energy potential [75].

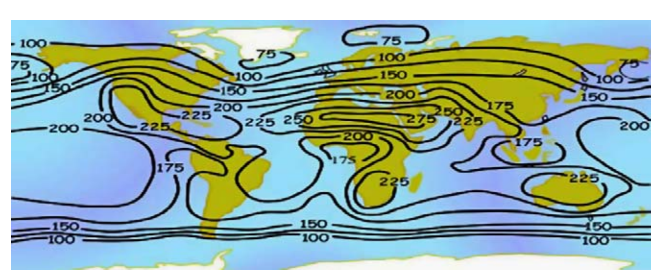

Fig. 3. Global solar radiation pattern [74].

PV/wind energy systems [22,50]. Photovoltaic array area, number of wind machines, and battery storage capacity play an important role in operation of hybrid PV/wind–diesel system while satisfying load [1]. Celik [48] proposed a technique to evaluate feasibility of hybrid PV/wind energy system using synthetically generated weather data. Ding and Buckeridge [54] discuss the desired hybrid energy system consisting two or more renewable energy sources which has the advantage of stability, the objective of lighting pathway at the project site can be achieved by making use of the wind, solar and hydro energy sources. The information about local wind, a solar and hydro energy source indicates that a feasible hybrid energy system can be planned, modeled and designed for the above purpose. The collected data of the various energy sources was analyzed in order to plan for the structure of the system. Simulations and modeling were carried out over a period of 12 months, allowing the statistical information [45] about local weather to be truly representative. This model also allows an optimal capacity of the hybrid energy system to be determined. Khan and Iqbal [22] discussed a primary design and pre-feasibility analysis of a hybrid energy system for a household in or around St. John's, Newfoundland. He collected 1-year wind speed, solar radiation and power consumption data of a house in St. John's, Newfoundland which was used for the feasibility study of a hybrid energy system.

3. Unit sizing and optimization

After pre-feasibility study the selection of proper sizing of equipment is made based on weather data and maximum capacity. The unit sizing of integrated power system plays an important role in deciding the reliability and economy of the system. In this section, study by the different researchers discussing different methods to determining the wind generator capacity and the number of PV panels and other sources and number of battery needed for the stand-alone system is reviewed. Rahman and Chedid [30] gives the concept of the optimal design of a hybrid wind–solar power system for either autonomous or grid-linked applications. They Proposed linear programming techniques to minimize the average production cost of electricity while meeting the load requirements in a reliable manner, and takes environmental factors into consideration both in the design and operation phases. Markvart [43] described a procedure for determines the sizes of the PV array and wind turbine in a PV/wind energy hybrid system. Using the measured data of solar and wind energy at a given location, author employ a simple graphical construction to determine the optimum configuration of the two generators that satisfies the energy demand of the user throughout the year. Katti and Khedkar [9] develop the algorithm uses hourly average wind speed, insolation, and power demand to determine the wind/PV generation capacities required to meet the demand without loss of power supply probability (LPSP). Elhadidy and Shaahid [24–26] calculated optimum battery storage size for hybrid wind energy system by studying an impact of variation of battery storage capacity on hybrid power generation. Trade off between size of the storage capacity and diesel power required for the load, assuming a constant wind power output, was also reported by the authors. In 2006, Koutroulis et al. [19] presented a methodology for optimal sizing [31] of stand-alone PV/WG systems using genetic algorithms. They applied design approach of a power generation system, which supplies a residential household.

Optimum size of hybrid PV/wind energy system can be calculated on an hourly basis [17] or on the basis of daily average power per month, the day of minimum PV power per month, and the day of minimum wind power per month. Performance of hybrid PV/wind energy system was compared on hourly basis; by fixing the capacity of wind generators, yearly loss of load probability (LOLP) with different capacity of PV array and battery bank were calculated. Trade off curve between the battery bank and PV array capacity for given LOLP helps to find optimum configuration at least cost. They employs a linear programming techniques [34] to minimize the average production cost of electricity while meeting the load requirements in a reliable manner, and takes environmental factors into consideration both in the design and operation phases.

Various optimization techniques such as linear programming [20,51], probabilistic approach [64], iterative technique [53] dynamic programming [62], multi-objective genetic algorithm [19,6] were used by researchers to design hybrid PV/wind energy system in a most cost effective way. In order to calculate reliability/cost implications of hybrid PV/wind energy system in small isolated power systems. Karki and Billinton [4] presented a Monte-Carlo simulation approach. Samarakou et al. [10] compared results of two optimization techniques based on simplex and other algorithm for hybrid PV/wind energy system. They presented a method for assessment on the basis of loss of load probability (LOLP) to decide an optimal proportion of PV and wind generator capacities in hybrid PV/wind energy system; optimal system combination was selected on the basis of capital cost and annual autonomy level. Autonomy level of the system is defined in terms of LOLP and is been used to find system configuration [61]. Protogeropoulos et al. [34] have developed general methodology by considering design factor such as autonomy, for sizing and optimization. Ai et al. [42] has presented a complete set of math calculation methods for optimum sizing of PV/wind hybrid system. In this method, the more accurate and practical mathematic models for characterizing PV module, wind generator and battery are adopted; combining with hourly measured meteorological data and load data, the performance of a PV/wind hybrid system [15] is determined on a hourly basis; by fixing the capacity of wind generators, the whole year's LPSP (loss of power supply probability) values of PV/wind hybrid systems with different capacity of PV array and battery bank are calculated, then the trade-off curve between battery bank and PV array capacity is drawn for the given LPSP value; the optimum configuration which can meet the energy demand with the minimum cost can be found by drawing a tangent to the tradeoff curve with the slope representing the relationship between cost of PV module and that of the battery.

Yang [8] developed a novel optimization sizing model for hybrid solar–wind power generation system. To optimize the capacity sizes [29] of different components of hybrid solar–wind power generation systems employing a battery bank, the authors also calculated battery size requirements to achieve desired level of autonomy by using system performance simulation model. It is observed that for achieving high autonomy, a backup generator is required and in turn reduces battery storage capacity. Hancock et al. [61] discussed the approach to optimize hybrid PV/wind/battery system with conventional power plant and calculated optimal system configuration on the basis of Life cycle cost. National Renewable Energy Laboratory (NREL)'s, Hybrid Optimization Model for Electric Renewable (HOMER version 2.19) [73] has been used as the sizing and optimization software tool [72]. It contains a number of energy component models and evaluates suitable technology options based on cost and availability of resources. Analysis with HOMER requires information on resources, economic constraints, and control methods. It also requires inputs on component types, their numbers, costs, efficiency, longevity, etc. Sensitivity analysis could be done with variables having a range of values instead of a specific number.

4. Modeling of hybrid renewable energy system (HRES) components

Literature review reveals that over the last decades, HRES applications are growing rapidly and HRES technology has proven its competitiveness for remote area applications. It is observed that approximately 90% of studies reported are on design/economic aspects of HRES. However, fewer studies were reported on control of HRES. Utility interactive HRES [68] has yet not gained the popularity. It is expected that within the next few years HRES becomes competitive with utility grid power for wide spread distributed applications. Hence, there is a need to investigate potential and performance of PV and wind energy system to calculate level of penetration in existing networks of developed or developing countries in order to improve quality of power supply. The simulation results prove the operating principle, feasibility and reliability of this proposed system. Solar/diesel/battery hybrid power systems [23,67] have been modeled for the electrification of typical rural households and schools in remote areas. Kolhe et al. [13] elaborately discussed the analytical model for predicting the viability of hybrid PV/wind energy system with hydrogen energy storage for long-term utilization. The modeling [11,46] of different hybrid energy system components are given here as under.

4.1. Modeling of photovoltaic system

Solar energy conversion system depends upon the solar cell and photovoltaic module. The mathematical modeling of solar–photovoltaic system is discussed here as under.

The ideal equivalent circuit of a solar cell consists of a current source in parallel with a diode. The output terminals of the circuit are connected to the load. Ideally the voltage current equation of the solar cell [21] is given by

$$I_{\mathrm{pv}} = I_{\mathrm{ph}} - I(\mathrm{e}^{qV_{\mathrm{pv}}/kT} - 1) \tag{1}$$

where I_{ph} is the photo current (A), I_0 the diode reverse saturation current (A), q the electron charge = 1.6×10^{-19} (C), k the Boltzman constant = 1.38×10^{-23} (J/K); T the cell temperature (K).

The power output of a solar cell is given by

$$P_{\mathrm{PV}} = V_{\mathrm{PV}} I_{\mathrm{PV}} \tag{2}$$

where I_{PV} is the output current of solar cell (A). V_{PV} the solar cell operating voltage (V). P_{PV} the output power of solar cell (W).

The power–voltage (*P–V*) characteristic of a photovoltaic module operating at a standard irradiance of 1000 W/m and temperature of 25 °C shown in Fig. 4.

Also the input energy to PV system is solar radiation and total solar radiation [7] on an inclined surface is estimated as

$$I_{\mathrm{T}} = I_{\mathrm{b}} R_{\mathrm{b}} + I_{\mathrm{d}} R_{\mathrm{d}} + (I_{\mathrm{d}} + I_{\mathrm{b}}) R_{\mathrm{r}}, \tag{3}$$

where I_{b} and I_{d} are direct normal and diffuse solar radiations, R_{b}, R_{d} and R_{r} are the tilt factors for the beam, diffuse and reflected part of the solar radiations.

The total solar radiation thus estimated depends on position of sun in the sky, which varies from month to month. Hourly power output from PV system with an area A_{PV} (m^2) on an average day of jth month, when total solar radiation of I_{T} (kWh/m^2) is incident on PV surface, is given by

$$P_{sj} = I_{Tj} \eta A_{\mathrm{PV}} \tag{4}$$

where η is PV-system efficiency is given by

$$\eta = \eta_{\mathrm{m}} \eta_{\mathrm{pc}} P_{\mathrm{f}} \tag{5}$$

and the modular efficiency η_{m} is given by

$$\eta_{\mathrm{m}} = \eta_{\mathrm{r}}[1 - \beta(T_{\mathrm{c}} - T_{\mathrm{r}})] \tag{6}$$

where η_{r} is the module reference efficiency, η_{pc} is the power conditioning efficiency, P_{f} is the packing factor, β is the array efficiency temperature coefficient, T_{r} is the reference temperature for the cell efficiency and T_{c} is the monthly average cell temperature.

4.2. Modeling of wind energy system

The mathematical modeling of wind energy conversion system includes, wind turbine dynamics and generator modeling. Considered here for review a three-blade, horizontal-axis, and maintenance free wind electric generator is installed [33]. It converts wind energy into electrical energy. The wind power generation from the turbine can be predicted from the wind power equation discussed here as under.

The wind turbine is characterized by non-dimensional performance as a function of tip speed ratio. The output of mechanical power captured from wind by a wind turbine [44] can be formulated as

$$P_{\mathrm{t}} = \frac{-(C_{\mathrm{p}} \lambda \rho A V^3)}{2} \tag{7}$$

and torque developed by wind turbine can be expressed as

$$T_{\mathrm{t}} = \frac{P_{\mathrm{t}}}{\omega m} \tag{8}$$

where P_{t} is the output power, T_{t} the torque developed by wind turbine, C_{p} the power co-efficient, λ the tip speed ratio, ρ the air density in kg/m^3, A the frontal area of wind turbine, V the wind speed.

$$\lambda = \frac{\omega R}{v} \tag{9}$$

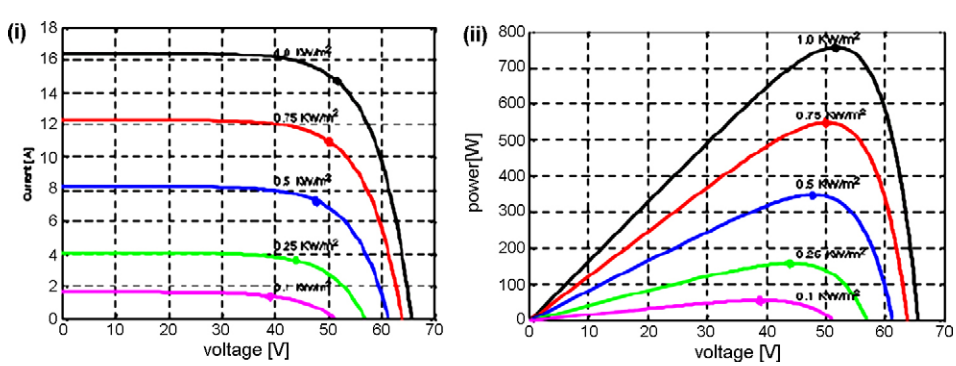

Fig. 4. (i) *I–V* characteristics of PV module and (ii) *P–V* characteristics of PV module.

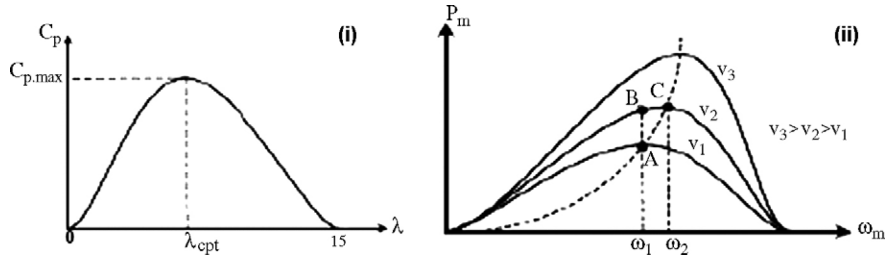

Fig. 5. (i) Power coefficient vs. tip speed ratio and (ii) output power vs. rotor speed for three different wind speed.

where ω is the turbine rotor speed in rad/s, R the radius of the turbine blade in m, and v the wind speed in m/s, respectively. Wind power curves are shown in Fig. 5.

Some researchers have focused on the different modeling technique for wind energy conversion system. Arifujjaman et al. [24,47] presented the dynamic modeling of small wind turbine with furling dynamics. Also such small wind turbines are based on permanent magnet generators and their speed can be regulated using the load control. The extraction of maximum power output from such wind turbines is investigated using tip speed ratio control and hill-climbing control methods. The system is simulated in Matlab/Simulink to determine a suitable control strategy. Borowy and Salameh [33] discussed the dynamic response of a stand-alone wind energy conversion system with battery energy storage to a wind gust. They proposed a mathematical model of each element of the stand-alone wind energy conversion system. The model variables are expressed in the $d-q$ rotor reference frame. The wind turbine was considered as the only source of power in this study. Using this model the system response to a recorded wind gust is investigated by calculating the generator current, the rectifier current, the load current, the battery charging current, and the battery voltage.

4.3. Modeling of diesel generator

To attenuate shortfalls in energy production during periods of poor sunshine, photovoltaic systems require a backup diesel generator for increased system availability and minimum storage requirements. The choice of diesel generator depends on type and nature of the load. To determine rated capacity of the engine generator to be installed, following two cases should be considered:

1. If the diesel generator is directly connected to load, then the rated capacity of the generator must be at least equal to the maximum load, and
2. If the diesel generator is used as a battery charger, then the current produced by the generator should not be greater than CAh/5 A, where CAh is the ampere hour capacity of the battery.

Overall efficiency of diesel generator is given by [20]

$$\eta_{\text{over-all}} = \eta_{\text{breakthermal}} \times \eta_{\text{generator}}$$

Here $\eta_{\text{breadthermal}}$ is brake thermal efficiency of diesel-engine. Normally, diesel generators are modeled in the control of the hybrid power system in order to achieve required autonomy. It is observed that if the generator is operated at 70–90% of full load than it is economical [12]. In the absence of peak demand, diesel generators [37] are normally used for meeting load requirements and for battery charging.

5. Hybrid controller for energy flow and management

One of the main problems of the HES is related to the control and supervision of the energy distribution system. The dynamic interaction between the grid and/or the loads and the power electronic interface of renewable source can lead to, critical problems of stability and power quality in new system, that are not very common in conventional power systems.

Managing the flow of energy throughout the proposed system to assure continuous supply of the load demand is to be done. The main objective of the energy flow and management system is to supply the load with its full demand. The operating strategy for energy flow [35,36] in the system has been outlined before unit sizing and the same will be satisfied for efficient operation of integrated power system [14,60]. To overcome the problem of intermittent power generation, PV power systems may be integrated with other power sources. Fuel cells are an attractive option because of high efficiency, modularity and fuel flexibility; however, one main week point is their slow dynamics. On the other hand, current technology batteries by themselves are usually insufficient to provide the long-term energy that the increasing loads require. Hybrid systems composed of fuel cells and batteries can be integrated with PV power systems to provide uninterrupted high-quality power. The goal of this study is to design an effective power management system for a renewable based hybrid power system.

5.1. Using conventional approach

Conventional approach of controlling the power supply to the load according to demand were used in various hybrid systems. In the conventional approach power electronics based DC–DC converter are used for maximum energy extract from solar and wind energy sources and control the complete hybrid system. Some researchers have used different controlling technique [65] for different combination of hybrid energy systems. Here the reviews of different research paper are given as under.

Das et al. [21] proposes modeling of PV/wind/fuel cell hybrid energy system. In worst environmental conditions, when there is no output power from the wind or photovoltaic sources, the fuel cell will operate at its rated power of 10 kW. They proposed a simple and economic control method with DC–DC converter is used for maximum power point tracking and hence maximum power extraction from the wind turbine and photovoltaic array. The individual DC–DC converters are in turn connected to a single PWM voltage source inverter, which holds the output voltages of all the converters at a fixed value by balancing input and output power of the DC links. All the energy sources are modeled using PSIM software tool to analyze their dynamic behavior. The complete hybrid system is simulated for different operating conditions of the energy sources. Abdin and Xu [59] designed the control scheme for a wind energy conversion scheme using induction generators. The scheme consists of a three-phase induction generator driven by a horizontal axis wind turbine and interfaced to the utility through a double overhead

transmission line. A static VAR compensator was connected at the induction generator terminals to regulate its voltage. The mechanical power input was controlled using the blade pitch-angle. Both state and output feedback controllers are designed using MATLAB software to regulate the generator output. From the simulation results the response of closed loop system exhibited a good damping and fast recovery under different type of large disturbances.

In this series Bansal et al. [27,28] discussed an automatic reactive-power control of an isolated wind–diesel hybrid power system having an induction generator (IG) for a wind-energy-conversion system and synchronous generator (SG) for a diesel-generator (DG) set. Park et al. [56] presented the power compensation system for controlling energy flow through hybrid energy system according to load demand. Valenciaga and Puleston [12] and Onar et al. [7] developed the controller for hybrid power systems. In [12] the supervisor control developed three modes of operation and they used sliding mode control methods [32] for controlling the hybrid system.

5.2. Using expert system

The control system for HES configurations should minimize fuel consumption by maximizing power from the renewable sources. However, there are power fluctuations by the variability of the renewable energy, which cause disturbances that can affect the quality of the power delivered to the load. To manage the flow of energy efficiently with good quality power, it is needed to develop the advance controlling technique in near future.

In few published literature artificial intelligent or expert systems are used to develop the controller for energy flow through hybrid systems. Here some papers are taken for review purpose of hybrid energy controlling process. El-Shater et al. [69] discussed the Energy flow and management of a hybrid wind/PV/fuel. In this paper, an energy system comprising three energy sources, namely PV, wind and fuel cells, is proposed. Each of the three energy sources is controlled so as to deliver energy at optimum efficiency. Fuzzy logic control technique is employed to achieve maximum power tracking for both PV and wind energies and to deliver this maximum power to a fixed DC voltage bus. In 1993, Fung et al. [55] presented, a solution to the short term generation scheduling problem in a hybrid energy system, used in remote area power supply (RAPS). Instead of extending the main electricity grid, RAPS systems are economical alternatives for the supply of electrical energy to consumers in remote areas. They proposed a new approach based on fuzzy-logic (FL) and genetic algorithm (GA) techniques [5,40,63] for the scheduling of the battery and the diesel generator of a RAPS system. They also have developed two methods. One was based on a pure genetic algorithm (PGA) approach, and the other was based on a combined fuzzy-logic and genetic algorithm (FGA). Hancock et al. [61] describes a method for optimizing and controlling the operation of stand-alone hybrid power systems containing some combination of auxiliary generator, PV generation and storage battery. They have developed and analyzed a method for optimizing the operation of hybrid RAP (remote area power supply) systems.

On the basis of above literature review, researchers focused on the design, operation, and performance analysis of individual system for HRES find that, In order to predict performance, individual components should be modeled first and then their mix can be evaluated, to meet the demand reliably.

6. Future trends for design and operation of hybrid energy system

This system can be considered for a sustainable hybrid energy system, designed on two modes. One is standalone and other is grid-assisted mode. In stand-alone mode, it draws power from the wind–solar hybrid energy system. In the grid-assisted mode, when the hybrid system is unable to feed the power, it automatically takes the grid power. If the site-specific data is not available, one may use nearest meteorological station data in designing the system. The system voltage variation, the frequency, waveform and power factor at the time of grid connection, must be maintained within the limits. One can improve the power quality depending upon the local conditions. Hybrid energy flow is controlled using power electronic converters. This energy would be useful in many applications such as ship power systems, electric hybrid vehicles, telecommunication industries, rural electrification etc.

Further R&D improvements in solar PV and wind technologies will reduce the cost of renewable energy sources. The cost of conventional energy resources is increasing every year. This system is going to be economical in future. Besides the cost, the environmental benefits are likely to facilitate the widespread use and acceptance of these systems.

As discussed in the previous section, the inclusion of artificial intelligence as part of the energy management system in near future, promises to optimize the operation of hybrid energy. The performance of modular hybrid energy systems can be improved through the implementation of advanced control methods in a centralized system controller. Optimum resource allocation, based on load demand and renewable resource forecast, promises to significantly reduce the total operating cost of the system. The application of modern control technique to supervise the operation of modular hybrid energy systems allows the utilization of the renewable resource to be optimized. Advanced control techniques will also improve the performance of such systems by improving energy management.

7. Conclusions

The hybrid energy systems are recognized as a viable alternative to grid supply or conventional, fuel-based, remote area power supplies all over the world. The literature review reveals that, renewable energy based low emission hybrid systems are not cost competitive against conventional fossil fuel power systems. However, the need for cleaner power and improvements in alternative energy technologies bear good potential for widespread use of such systems. Moreover, the rural households in industrialized and less developed countries attach high value to a reliable, limited supply of electricity. Community facilities such as rural hospitals, schools, telecommunication and water pumping stations can contribute significantly to the welfare of people and rural development. While it is recognized that technology can only be one aspect of community development, the renewable energy systems have demonstrated the potential to provide support in some of the basic infrastructure needs in remote and urban areas for different application.

Although the cost reduction and technological development of hybrid energy systems in recent years has been encouraging, still they remain an expensive source of power. To allow the widespread application of this emerging technology, there is a need for further R&D improvements in solar PV and wind technologies that can reduce the cost of hybrid system. The cost of conventional energy resources is increasing every year, but the receding trend in the cost of renewable energy technologies because of its widespread use is encouraging factor, projecting RES system an economical means of power generation in future for many standalone applications.

This may finally be concluded that the hybrid energy system combining variable speed wind turbine and PV array generating

system may be integrated to supply continuous power to the load with optimal design of hybrid controller. The hybrid controller manages the power flow between the systems components such that the energy cost is minimum and load requirements could be met round the year.

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